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RANGELAND WATERSHED MANAGEMENT

.....A Review

PRECIPITATION PATTERNS

INTERCEPTION

INFILTRATION

RUNOFF AND SEDIMENT PRODUCTION

Gerald F. Gifford

Agricultural Experiment Station
Max C. Fleischmann College of Agriculture
University of Nevada
in cooperation with
Bureau of Land Management

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TO : State Directors, Alaska, Arizona, California, Colorado, Idaho, Montana, New Mexico, Oregon, Utah and Wyoming

FROM : State Director, Nevada

SUBJECT: Publication - "Rangeland Watershed Management....A Review"

Attached, for your information, is one copy of the subject publication.

This report was accomplished by the Nevada Agricultural Experiment Station in cooperation with the Bureau of Land Management and contains research data on precipitation patterns, interception, infiltration, runoff and sediment production on range landscapes in the West.

D L Piper

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RANGELAND WATERSHED MANAGEMENT

A REVIEW

I. Precipitation Patterns

II. Interception

III. Infiltration

IV. Runoff and Sediment Production

Gerald F. Gifford[1/]

Nevada Agricultural Experiment Station

Project 3-37-5483

in cooperation with

Bureau of Land Management

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PREFACE

Rangeland hydrology, or rangeland watershed management, has been a neglected phase of past range research efforts. This lack of interest in the hydrology of rangelands (land producing native forage for animal consumption, and lands that are revegetated naturally or artificially to provide a forage cover that is managed like native vegetation) is probably a direct result of public apathy. This apathy reflects lack of knowledge concerning importance of rangelands in the receipt and disposition of water, especially in those areas west of the 100th meridian.

This is a review of research pertaining to precipitation patterns, interception, infiltration, and runoff and sediment production on range landscapes in the West. The organization of contents, which approaches a subject-area-author bibliography, is hopefully one which will allow the reader to review specific subjects in a minimum of time.

Perhaps one of the most significant features of this review is the lack of meaningful information. Information that can be reviewed, extracted, and finally extrapolated to areas of similar environments must contain some statement as to reliability of data, i.e., statistical significance, return intervals (or the frequency with which similar results might be obtained), methodology used to obtain data, and conditions during study. Some, or all, of these requisites to adequate interpretation were missing from various papers included in this review. Therefore, generalities abound throughout.

Techniques used are a prime consideration when trying to interpret hydrologic research findings, especially when extrapolations are made to actual field situations. For example, an infiltration (or runoff) study might involve one of three approaches: (1) a sprinkler type rainfall applicator; (2) an artificial flooding or ponding approach; or (3) infiltration under natural rainfall. If a sprinkler is used, it might be any one of a dozen different kinds which produce various drop sizes, intensities and aerial coverage. The latter often affects size of plot used. Sprinkler type infiltrometers are an effort to duplicate natural falling raindrops from a particular type storm and thereby obtain a more realistic measure of infiltration.

The flooding or ponding approach, as for example with ring infiltrometers, is generally a poor technique if some approximation to infiltration under natural rainfall is to be obtained. Comparative differences, however, can be obtained by this method and the technique is probably suited for instances where natural flooding does occur, as in flood irrigation or within contour trenches, etc.

Infiltration under natural rainfall can be derived from data on small plots or entire large watersheds. Some people prefer this approach, with the larger the plot the better. Generally one tries to derive infiltration values for homogeneous units of vegetation and soil.

Therefore, be alert. Generalities derived from Wyoming data may not hold for Arizona situations, and vice versa. Future studies should help to better or redefine present viewpoints (or in many cases merely hypotheses) concerning hydrologic parameters of rangeland environments.

Finally, the author gratefully acknowledges the following who offered criticisms and suggestions upon portions of the manuscript: Dr. George Coltharp, Dr. Richard Meeuwig, Dr. C. M. Skau and Dr. L. A. Stoddart.

RANGELAND WATERSHED MANAGEMENT

A REVIEW

Introduction: Precipitation, interception, overland flow, runoff, sediment production, and groundwater flow, and laws governing these phenomena, have been of interest for centuries. The voluminous literature available on the subject, especially in agriculture, attests to this interest.

The "conservation" (husbandry) of soil and water on agricultural lands has been studied sufficiently so that desired objectives can be knowingly attained by application of land-treatment practices and water-control structures on individual farms and upstream drainageways (Wischmeier and Smith, 1965). This is not true for wildland situations, even though information on the hydrologic behavior of forest and rangelands and the relationships of land use to water yield and streamflow has been accumulated through the studies, experiments, and observations of competent scientists over a long period of years. The reason for this is the enormous complexity presented in wildland environments with respect to hyrologic interpretation. This is further complicated by lack of established research methodology as well as insufficient funds for gathering basic hydrologic data necessary to design meaningful studies.

Chapline (1929), Forsling (1932), Bailey and Connaughton (1936), U. S. Forest Service (1940), Allred (1940, Lawhon (1947), Munns (1947), Lassen, Lull and Frank (1952), Harper (1953), and McArdle (1960) have previously reviewed various aspects of rangeland hydrology. Love (1958) discussed some concepts of rangeland watershed management as derived from small plot watershed studies in grasslands. Other reviews (Storey, Hobba, and Rosa, 1964) emphasize the hydrologic processes undergone by water in places where it can be affected by forest and range vegetation.

The objectives of this discussion are expansion of the topic to include as many western rangeland situations as possible. Also, the purpose is to provide the reader with references for more detailed investigations, and to supply additional insight into basic and applied problems which have no concrete answers to guidelines.

The Rangeland Hydrologic Cycle

Precipitation patterns. Rangelands are governed by the same laws of physics and meteorology as are other land masses when considering the hydrologic cycle. This cycle (Ackermann, Colman, and Ogrosky, 1955; Gardner, 1965), described in all elementary hydrology textbooks, is driven by solar energy. Generally, rangelands are characterized by extremes in various components of the cycle, examples being low rainfall, high evapotranspiration potential, and low water yields.

Precipitation patterns are of particular interest to the rangeland watershed manager. Annual variation in the West, expressed as coefficients of variation of annual precipitation, varies from 15 to 20 percent in the Northwest up to 55 to 60 percent in the extreme Southwest (Hershfield, 1962). Individual storms show large variation in total amount, duration, distribution, and intensity. Though general precipitation patterns are of interest to range managers, the discussion here will be limited to individual storm behavior since these are of most interest and concern to the watershed manager.

Information is limited from which storm behavior can be determined and how such behavior varies with season, time of day, and topography on rangelands. Generalizations are possible from data collected by the U. S. Weather Bureau, and attempts to describe selected climatic environments result (Wernstedt, 1960). Techniques have been devised for extrapolating point measurements of rainfall to adjacent ungaged rangelands (Court, 1961; Peck and Brown, 1962; Stidd, 1966), but such techniques are at best ball-park estimates.

Common assumptions are that the following phenomena occur during individual storms (Sharp and Holtan, 1942):

1. Water is supplied at varying rates and amounts as rainfall.

2. Vegetation, litter, etc. intercept a part, or all, of the rainfall.

3. A part of the rainfall evaporates before, or after, reaching the vegetation, litter or soil.

4. All, or part of the rain reaching the soil may be absorbed as infiltration at varying rates, equal to, or less than the rate of "effective rainfall" (effective rainfall means that portion reaching the soil).

5. There may be some loss by transpiration from plants.

6. When the effective rate of rainfall exceeds the infiltration rate, a part of the excess rainfall may collect in depressions and part adhers to the soil surface. They are both included in the term depression storage.

7. After the beginning of rainfall-excess, detention (surface-storage above depression storage and adhesion), begins to accumulate. Detention is the hydraulic head affording the motivating force for runoff.

8. Simultaneously with the accumulation of detention, surface-runoff begins.

9. Water infiltrated into the soil may reappear on the surface or in the streams as runoff.

10. Surface-runoff from some portions of the area may be absorbed by lower portions of the area before reaching the outlet.

11. Finally, the excess of supply over losses will appear as surface-runoff at the outlet of the area under study.

Some detailed information has been derived from studies in the Southwest. These studies (McDonald, 1956; Fletcher, 1961; Osborn and Reynolds, 1963; and Kincaid, Osborn and Gardner, 1966) concentrate on individual storms, and the following important characteristics have emerged:

1. Most convective storms in the region represented by these study areas are of short duration, low volume, and limited areal extent.

2. Comparatively few storms produce channel flow.

3. Runoff-producing storms, defined as those that result in channel flow, are of relatively high intensity. Such storms cause most of the floodwater damage, surface erosion, arroyo formation, and sediment deposition.

4. Approximately 65 to 70 percent of the annual precipitation, and all of that producing runoff, falls during the summer.

5. Point frequencies based on records from a few scattered gages are shown to be inadequate for the prediction of expected areal distributions, volumes, and intensities of convective rainfall necessary for hydrologic planning of work on small watersheds.

6. The rainiest summer hours are from 1700 to 2100 local time.

7. Suitable predictions for convective rainfall parameters for specific localities may be developed from records from intense recording rain gage networks, operated over a relatively few years.

Intensity values from selected experimental watersheds included in the above studies are presented in Tables 1 and 2.

Table 1. Number of times intensities were exceeded for given periods for storms greater than 0.75 inch on four Safford watersheds*.

Maximum intensity (in/hr)	Time intervals (minutes) 5	10	15	20	25	30
8.0	1					
7.0	4	1				
6.0	6	3	1	1		
5.0	15	6	3	1		
4.0	35	19	9	4	1	
3.0	70	46	23	15	8	1
2.0	95	90	77	61	25	3
1.0	105	105	105	103	102	44

* Twenty-two years of record; total of nine 12-hour recording rain gages on four watersheds.

Table 2. Number of times intensities were exceeded for given periods for storms greater than 0.65 inch on the Montao watersheds*.

Maximum intensity (in/hr)	Time intervals (minutes) 5	10	15	20	25	30
8.0						
7.0						
6.0	1	1				
5.0	1	1	1			
4.0	4	2	1	1		
3.0	14	6	2	1	1	
2.0	28	17	12	4	2	
1.0	38	38	38	37	25	3

* Twenty-two years of record; total of five 12-hour recording rain gages.

A detailed study on the Reynolds Creek watershed, in the Owyhee Mountains of southwestern Idaho, reinforced previous observations that rain gage densities of one or two per 100 square miles are not adequate to determine the probability of infrequent high intensity rains within a reasonable time (Cooper, 1967). Other findings in the study were:

1. Practically all high intensity rain during the study period (4 years) occurred from April through October.

2. High intensity rainfall resulted chiefly from spring and summer storms with a strong convective component. Almost all intense storms during the study period began between 1600 and 2200 local time.

3. There was no apparent relationship between elevation and peak intensity or between elevation and total amount falling at any given intensity. This apparent lack of relationship between rainfall intensity and elevation suggested that data from accessible valley stations could be used to estimate the relative occurrence of high intensity rains throughout an area of appreciable range in elevation.

Table 3 shows monthly distribution of high intensity storms during the study period.

Table 3. Monthly distribution of high intensity storms, 1961-1964.

Month	Percentage of all high intensity events	
	Over 0.5"/hr	Over 2.0"/hr
January	1.5	0.0
February	1.5	3.5
March	0.0	0.0
April	4.5	3.5
May	22.0	24.0
June	33.0	38.0
July	3.0	7.0
August	18.0	24.0
September	4.5	0.0
October	3.0	0.0
November	7.5	0.0
December	1.5	0.0
Total	100.0	100.00

Price and Evans (1937), Lull and Ellison (1950), and Croft and Marston (1950) have studied rainfall characteristics along the Wasatch Mountain front in Utah. The following statements are extracted from the paper of Croft and Marston:

"The multiple records of ... four storms show there was considerable variation in rainfall depth and intensity from place to place during individual bursts (from a given storm) and between bursts. Though greatest depths and intensities tended to occur near mountain crests in three of the storms, their occurrence in a deep canyon bottom in one of the four storms indicates no consistent relationship to relief. It appears, in other words, that high-intensity rainfall may occur on all portions of this mountainous area. Moreover, the records show that rainfall rates in excess of eight inches per hour may occur on an area of about one square mile and that rates in excess of six, four, and two inches per hour may occur over as many as six, 25, and 36 square miles, respectively...

"Although these mountain and valley intensity data are by no means conclusive, they strongly suggest that higher rainfall intensities may be expected on the windward slopes of the Wasatch Mountains than in the adjacent windward valleys."

Hershfield (1963) has briefly reviewed other research programs in the United States which promise to yield important storm behavior information. This information should provide, for one thing, new relationships fundamental to spacing raingages for hydrologic investigations.

It is evident that little is known about storm characterization, a most important input variable in the hydrologic cycle on rangelands. In most cases, information must be extrapolated to fill voids where adequate data do not exist.

Interception. Few studies are available which concern themselves with interception losses from brush, grass or other herbaceous vegetation types. Interception loss, the second abstraction from precipitation (the first being evaporation of drops during time of fall), is water returned to the atmosphere through evaporation from plant or litter surfaces or absorbed by the plant.

Crouse, Corbett, and Seegrist (1966) have briefly reviewed literature in this field. Past studies indicate variable precipitation amounts are lost via interception. Apparently, during major storms, most of the precipitation over rangeland vegetation actually reaches the ground by throughfall, foliage drip, or by flowing down the stems (stemflow).

The study by Crouse, Corbett, and Seegrist indicated that water storage capacity of grasses was proportional to the product of average height and percent of ground cover. Total interception loss for a storm was a function of the storage capacity and the number of showers per storm. Actual interception losses for storms with total rainfall greater than the storage capacity of the plants involved varied from .01 to .35 inch. Merriam (1961) tabulated surface storage potentials for several species of grass and his tabulation appears in Table 4.

Table 4. Surface storage or closely related quantities for grass.

Species	Description of plant	Term used	Storage inches	Source
Big bluestem	Dense stand, 2 ft high	Maximum interception capacity	0.092	Clark (1940)
Buffalo grass	8 in high, in bloom, many stolons	Maximum interception capacity	0.065	Clark (1940)
Slough grass	Nearly complete cover, few stems, lower leaves shed	Maximum interception capacity	0.033	Clark (1940)
Bluegrass	Maximum vegetative development	Total interception*	0.040	Haynes (1940)
Range mix†	10 in high (1500 lb/acre, air dry when 16 in high)	Interception storage‡	0.041 to 0.048	Burgy and Pomeroy (1958)
Annual ryegrass	Uniform stands, 4 to 19 in high (See Table 2)	Surface storage	0.017 to 0.111	Merriam (1961)

* Average of 4 storms with a total of 0.82 inches rain.
† Principal species were tall fescue and soft chess.
‡ Storage 0.01 inch greater than that shown was achieved with application of misty rain.

Studies by Rowe (1948) and Hamilton and Rowe (1949) in the chaparral type of central and southern California found that annual loss of rainfall through interception ranged from 1.7 to 3.9 inches (overall average amounted to about 8 percent of the average annual rainfall) depending on the total annual rainfall and the character of storms producing it. Throughfall, stemflow, and interception loss were generally directly proportional to storm size. For small storms, the interception loss was as much as 50 to 75 percent, and for large storms as little as 3 to 6 percent of the gross rainfall. Another study (Rowe and Colman, 1951) provided similar results. Kittredge (1939) found that chaparral forest floor in the San Gabriel Mountains retained 0.06 to 0.26 inches of water.

Townsend (1966) found retention-storage of chaparral leaves on the east side of the Sierra Nevadas varied from .01 to .07 inch. Grah and Wilson (1944) found that interception storage capacity for *Baccharis pilularis*, an evergreen brush species, varied between .02 and .06 inch.

Skau (1964) and Collings (1966) have derived formulae for estimating throughfall (and indirectly obtaining interception) for Utah and alligator juniper of Arizona.

Infiltration. Once a raindrop reaches the soil surface, it must ultimately infiltrate the soil, evaporate, or become a part of overland flow and eventual runoff. The actual role of infiltration in the hydrologic cycle was probably first recognized by Horton (1933). This infiltration referred to the movement or passage of water through the soil surface. Once in the soil, water movement is defined as percolation. The rate at which water can enter the soil is dependent on many factors, among which may be litter and rock cover, canopy coverage, surface crusting, rainfall energy, quantity of coarse material in soil surface, advancing contact angle, particle coatings, slope, soil texture, bulk density and percent noncapillary porosity. Other factors are percent organic matter, parent material, micro-biological activity, wind action, temperature of soil and air and water, shrinking and swelling of colloids, season of year, successional stage and age of vegetative cover, exchangeable ions present, silica-sesquioxide ration, degree of aggregation, moisture content of soil, and soil structure. Horton recognized a maximum and minimum capacity. The maximum capacity for any given rain occurs at the beginning of the rain. This rate decreases rapidly at first because of changes in the structure of the surface soil and because of increases in surface soil moisture, and then gradually approaches a somewhat stable minimum. The minimum infiltration capacity approaches the percolation rate of the soil profile.

The infiltration phase of range hydrology has received relatively more attention than have other related subjects over the years. Numerous devices have been designed to study infiltration under natural and artificial conditions (Pearse, 1936; Pearse and Bertelson, 1937; Arend and Knight, 1940; Rowe, 1940; Wilm, 1943; Evanko, 1950; Friedrich, 1951; Dortignac, 1951; Bondurant, 1957; Barnes and Costel, 1957; Adams, Kirkham and Neilsen, 1957; Krimbold and Shahori, 1957; Packer, 1957; Meyer and McCune, 1958; Johnson, 1963; U. S. Geological Survey, 1963; Steinhardt and Hillel, 1966). Results from various studies reported in the literature are given below by state and soil type:

ARIZONA

Igneous soil vs calcareous soil, Walnut Gulch. (Kincaid, Gardner, and Schreiber, 1964) Soil in a grassland area showed greater and more abrupt responses to rainfall at the 6- and 18-inch depths than a calcareous soil supporting a shrub cover. Combination of shrub and half-shrub over-story with ground cover of surface gravel, litter, and grass showed the best observed relation to cumulative short-time infiltration. A fair curvilinear relation was demonstrated between crown-spread of shrubs and half-shrubs and final infiltration capacity.

Various Arizona desert soils. (Beutner, Gaebe and Horton, 1940) Hydrographs for experiments (using Soil Conservation Service D-1 sprinkler apparatus) that cover a variety of examples of different sites with different slopes, soils and duration of experiments were studied. All the infiltration-curves had similar shapes, beginning with high values and declining rapidly for the first 10 minutes, after which they continue to decline slowly until a nearly constant infiltration rate is reached. Final infiltration rates on "dry" runs (rainfall applied to soil in the dry condition) varied from 0.28 to 2.22 in/hr., and on "wet" runs (soil at "field capacity" to start) from 0.18 to 1.29 in/hr.

Granitic soils near Parker Creek. (Hendricks, 1942) Two lysimeters were utilized for 2 years to study the effect of grass litter on infiltration. Results indicated that more effective use of rainfall can be had on semi-arid rangelands if grazing is handled to allow for the accumulation of grass litter. Retarding runoff affords greater opportunity for rain water infiltration. Such also provides insulation for ground surfaces, lessening evaporation loss of soil moisture.

Parker Creek Watershed, above Roosevelt Dam. (Sykes, 1938) Examination of the hydrograph from a moderately intense winter storm indicated the average intensity of winter rainfall seldom exceeds the infiltration rate on the mountainous parts of watersheds with natural or fairly good vegetation ground-cover.

CALIFORNIA

Some typical upland watershed soils. (Scott, 1956) Single-ring infiltrometer data were collected in central California on soils derived from coarse-textured granite, fine-textured basic igneous, consolidated sedimentary, and mixed alluvium rocks. The effect of burning and the presence of ash did not render the soil of the burned areas impervious to water. The difference in relative infiltration rates favored the burned areas in all cases immediately following a fire and with only one exception a year later.

Another study on two typical upland soils, (Scott and Burgy, 1956), indicates that heat and burning brush on Hugo soil (shale derived and covered with ceanothus and chamise) have resulted in measurable changes in aggregation and permeability in the surface layers. These changes produce appreciable increases in infiltration rates. On Aiken soil (derived from basic igneous rocks) these effects are not so pronounced.

Loam soil. (Burgy and Scott, 1952) The authors concluded from field and laboratory studies that infiltration rates on soils tested may be influenced by burning of certain brush species, namely chamise *(Andenostoma fasciculatum)* and buckbrush ceanothus *(Ceanothus cuneatus)*, and the presence of ash on the surface in two ways, namely, aggregation of soil particles and chemical changes within the soil. No decrease in infiltration rates occurred on the soils tested.

Various soils, San Dimas Experimental Forest. (Krammes and Debano, 1965) Field surveys and exploratory laboratory studies on soil non-wettability demonstrate that this condition is a widespread phenomenon in burned brushland soils of southern California. The non-wettability appears to result from soil-organic interaction.

A later paper (Debano and Krammes, 1966) indicates that temperatures of 800 and 900 degrees applied for 20 minutes completely destroy the non-wettable property. Less intense treatments produced an extremely non-wettable condition. The authors speculate that decreased infiltration, increased surface runoff, and erosion from burned southern and central California watersheds could be the result of this relationship.

Sandy clay loam. (Rowe, 1948) From measurements of duration and intensity of rainfall for storms and phases of storms in which no surface runoff was produced, and for those which produced surface runoff, repeated annual burning in the woodland chaparral type was found to destroy 95 percent of the average infiltration capacity of the soil under natural rainfall.

Results obtained using the North Folk infiltrometer closely paralleled results under natural rainfall. Average results of these infiltration capacity tests were:

Undisturbed plots:
- Brush-covered soil . . . . . 6.00 in/hr
- Grass-covered soil . . . . . 3.00 in/hr

Annually burned plots:
- Denuded soil . . . . . 0.16 in/hr

These tests provided further evidence of a very great decrease in infiltration capacity of the soil on annually burned plots.

COLORADO

Granitic alluvium soils. (Dortignac and Love, 1961) Studies on the Manitou Experimental Forest with the Rocky Mountain infiltrometer indicate that infiltration rates vary with cover types on ponderosa pine types. Average final infiltration rates for various years and cover types are given in Table 5.

Table 5. Average Final Infiltration Rates.

Year	Grassland	Pine-grass	Pine-litter
	- - - - - (inches/hour)- - - - -		
1941	1.98	1.96	2.51
1942	1.72	1.86	2.10
1946	1.41	1.91	2.67
1952	1.59	1.96	2.07

Protection from cattle grazing provided recovery of infiltration rates, the recovery period covering 6 years on pine-grass sites and 13 years on grassland sites. Infiltration rates of the granitic alluvium soils on grassland and pine-grass sites could be estimated by measuring the quantity of dead organic material and noncapillary pores in the surface soil.

Soils derived chiefly from granite. (Johnson and Niederhof, 1941) In this study, conducted near Woodland Park, 1/200-acre plots and simulated rainfall were used to study surface runoff and erosion while plots 1 ft^2 were used to study influence of various plant species on infiltration. Table 6 summarizes infiltration rates for soils under various plant species and their comparison with bare soil. Of the 14 plant species compared to bare soil, two species increased the infiltration capacity of the soil, two species decreased it, and 10 species had no significant effect. Plant densities ranged from 4.8 to 9.2 percent.

Runoff under two rainfall intensities (2 in/hr and 4 in/hr) was greatest on the abandoned field type (10 percent slope), intermediate on valley bunchgrass (10 percent slope), and least on the mountain bunchgrass type (40 percent slope). Plots on the steeper slopes had significantly more sand and gravel and less silt, clay and colloids than the plots on gentler slopes. Erosion was most rapid on abandoned fields, intermediate on mountain bunchgrass, and least on the valley bunchgrass type.

Mancos shale hill slopes. (Schumm and Lusby, 1963) An analysis of precipitation and runoff data reveals that average runoff and the ratio of runoff to precipitation are less in the spring than in the fall, reflecting seasonal changes in soil characteristics. Therefore, seasonal changes in the soil, which cause a seasonal change in infiltration capacity, not only control the rate and process of hill slope erosion, but also significantly affect the hydrologic characteristics of small drainage basins.

Table 6. Infiltration rates for soils under various plant species and their comparison with bare soil.

Condition	Year	Plots	Infiltration capacity	Standard error 1/	Plant species vs. bare soil 2/
		No	In/hr	In/hr	In/hr
Abandoned fields					
Hordeum jubatum	1937	18	1.66	0.18	-0.15
Agropyron pauciflorum	1937	18	1.45	0.22	-0.36
Stipa robusta	1937	18	1.61	0.13	-0.20
Artemisia canadensis	1937	18	2.00	0.18	+0.19
Artemisia frigida	1937	18	1.93	0.30	+0.12
Bare soil	1937	18	1.81	0.18	----
Polygonum aviculare	1938	30	2.03	0.13	-0.64 3/
Penstemon unilateralis	1938	30	4.32	0.31	+1.65 4/
Helianthus petiolaris	1938	30	2.36	0.21	-0.31
Cirsium undulatum	1938	30	2.51	0.25	-0.16
Astragalus sp.	1938	30	2.42	0.27	-0.25
Bare soil	1938	30	2.67	0.24	----
Valley bunchgrass					
Muhlenbergia montana	1937	36	2.36	0.12	+0.56 4/
Festuca arizonica	1937	31	1.88	0.15	+0.08
Bare soil	1937	31	1.80	0.15	----
Grama (sub-type)					
Bouteloua gracilis	1937	30	1.81	0.12	-0.46 3/
Bare soil	1937	30	2.27	0.13	----
Mountain bunchgrass					
Arctostaphylos uva-ursi	1938	17	9.67	1.01	----
Festuca arizonica	1938	30	6.00	0.70	----
Muhlenbergia montana	1938	31	3.16	0.28	----

1/ Standard error of the mean infiltration rate.

2/ This comparison is expressed as the difference between infiltration capacities of the soil occupied by the plant species and bare soil.

3/ Significant.

4/ Highly significant.

Various soils of some mountain grasslands. (Turner and Dortignac, 1954) The Rocky Mountain infiltrometer was used to sample various conditions on four national forests in western Colorado. Observations were made in six common plant-cover types. Results are summarized in Table 7.

Table 7. Ground cover, herbage production, infiltration rates, and measured erosion for cover types.

Cover Type	Bare soil	Live vegetation		Litter	Infiltration rate	Total erosion	Soil type
		Grass	Weeds				
	Percent	Lb/A	lb/A		In/hr	Lb/A	
Dense Thurber fescue	6	2,034	426	10,238	4.7	76	Loam to clay loam
Open Thurber fescue	19	1,298	640	9,306	3.6	646	Loam to clay loam
Bluegrass	14	1,031	532	1,223	1.5	455	Silty clay to clay loam
Needlegrass	38	470	608	1,754	3.2	1,068	Loam to clay loam
Lush weed	28	337	1,553	2,167	4.4	788	Loam to clay loam
Poor weed	58	184	1,117	512	2.9	4,375	Loam to clay loam

IDAHO

Various soils, Boise River Watershed. (Pearse and Woolley, 1936) This study indicated a close relationship between the absorption rate of water by the soil and the presence and character of the plant cover. In general, plots bearing a single plant absorbed water .0275 inch per minute faster than the adjacent barren plots (same soil type), an increase of 71.2%. An increase of 127% occurred in presence of fibrous-rooted species and 51.5% due to taprooted species.

MONTANA

Silty clay alluvium. (Branson, Miller and McQueen, 1962) Tube type infiltrometers and small plastic rings were used to study the consequences 10 years after contour furrowing and seeding an area to crested wheatgrass near Fort Peck, Montana. Three grazing intensities and two soil conditions were available for the study. Table 8 presents infiltration information gathered on the various sites. Infiltration rates were greater on semi-slick soils than on slick soils and decreased with an increase in grazing intensity. A decrease in mulch on the more heavily grazed areas and possibly an increase in soil compaction due to trampling may have caused the decrease in infiltration rates as grazing intensities increased.

Table 8. Infiltration rates determined by means of a rainfall simulating infiltrometer. The data are the result of single 1-hour runs and represent the slope of the curve when a uniform rate of infiltration was reached.

	Rainfall simulator dry soil (1958)				Rainfall simulator moist soil (1959)			
	Slick		Semi-slick		Slick		Semi-slick	
	Low	High	Low	High	Low	High	Low	High
Ungrazed								
Unfurrowed	.26	.69	(a)	(a)	.44	.44	(a)	(a)
Furrowed, seeded	.27	.38	1.50	3.60	.38	.38	.87	2.13
Lightly grazed								
Unfurrowed	.08	.18	.08	.17	.18	.20	.10	.44
Furrowed, seeded	.50	.52	1.25	1.80	.03	.22	1.20	1.72
Heavily grazed								
Unfurrowed	.20	.25	.13	.55	.56	.64	.26	.30
Furrowed, seeded	.23	.36	.40	.75	.42	.62	.30	.40

(a) This condition was not present within the exclosure.

NEBRASKA

Various grassland soils. (Duley and Domingo, 1949) Various types of grasses tested with a 16- x 72-inch sprinkler type infiltrometer were effective in inducing high (usually in excess of 1.4 in/hr on "dry" runs and 1.1 in/hr on "wet" runs) intake rate of water into the soil. Total cover, however, including live grass and associated litter, was more significant than kind of grass or soil type.

From this same study, on an area affected by overflow deposits and trampling by animals, intake rate on bluegrass land was reduced to a very low point (from a normal of 2.02 in/hr down to 0.14 in/hr under "dry" conditions and from a normal of 0.85 in/hr down to 0.13 in/hr under "wet" conditions).

Soils covered with native sod. (Duley and Kelly, 1939) Sprinkled plots 1/200th of an acre in size established that soils covered with native sod gave a much higher intake rate of water than bare soils and they maintained this higher infiltration rate throughout the most extended test.

Three great soil groups. (Mazurak and Conard, 1959) Using cylinder ring infiltrometers, the authors found cool-season grasses generally had a more favorable effect on soil structure, with respect to water entry into soil during August, than warm-season grasses. *Agropyron desertorum*, a cool season grass, maintained a high rate of water entry into soil in all three great soil groups.

Silt loam, chernozemic soil near North Platt. (Mazurak, Kriz, and Ramig, 1960) Double cylinder infiltrometers were used to study the rates of water entry as affected by age of perennial grass sods. Two species of grass were used, *Agropyron intermedium* and *Bromus inermis*. Only the age of grass stand showed any statistical significance in the ratio of water entry, $\frac{10 \text{ min}}{120 \text{ min}}$. Plots cropped for 8 years to grasses approached the soil structural condition of plots in grass for 20 years. Other properties associated with soil structure showed that bulk density of the surface 3 inches of soil was significantly decreased by the increase in age of grass stand, the differences in the percent air-filled pores at 60-cm. tension or at field capacity, were not statistically significant.

NEVADA

Cobbly-sandy loam derived from andesite. (Haupt, 1967) Small plots (4 x 6 feet) were used in conjunction with a modified type - F infiltrometer to study physical effects of forest and meadow vegetation on soil freezing and snowpack characteristics and the hydrologic effects of simulated winter rainstorms on snowmelt, infiltration, overland flow, and soil movement. The plots were located 17 miles northwest of Reno, near Dog Creek, a tributary of the Truckee River.

Results indicated that plants, litter, and snow cover generally dissipate raindrop energy and increase infiltration, but exposed rock usually accelerates overland flow and erosion. Soil losses from snow-covered plots, regardless of vegetative cover, were practically nil. Stalactite soil frost promoted infiltration while porous concrete frost usually reduced infiltration on burned or sparsely vegetated sites but did not impair infiltration where plant and litter cover was appreciable. A rapidly melting snowpack over soil containing dense frost may accelerate on-site runoff. Tables 9 and 10 give infiltration rates, overland flow, and soil eroded in summer and winter under conditions of the study.

Table 9. Minimum infiltration rates in summer and winter.

Forest floor condition	Minimum infiltration			Surface permeability in winter
	Summer	Winter in/hr	Difference	
Bitterbrush				
1	0.66	0.90	+0.24	More permeable
3	*0.88	1.04	---	---
Sparse grass				
2	0.44	0.35	-0.09	Less permeable
		0.46	+0.02	More permeable
4	0.48	*0.96	*+0.48	More permeable
Pine litter				
5	0.67	1.03	+0.36	More permeable
7	0.65	*1.12	*+0.57	More permeable
Burned pine litter				
6	0.68	0.30	-0.38	Less permeable
8	0.76	*1.07	*+0.31	More permeable
Rocky-furrowed				
9	0.96	*1.10	*+0.14	More permeable
12	0.88	*1.01	*+0.13	More permeable
Rocky-bare				
10	0.48	---	---	
11	0.33	0.35	+0.02	More permeable

* Probably would have been greater at a higher rate of rainfall.

Table 10. Rates of overland flow and soil eroded in summer and winter.

Forest floor condition	Overland flow			Soil eroded			Soil erodibility in winter
	Summer	Winter	Difference	Summer	Winter	Difference	
	in/hr			tons/sq mi/hr			
Bitterbrush							
1	0.07	0.16	+0.09	4.3	0.5	-3.8	Less erodible
3	0.00	0.03	+0.03	1.4	2.5	+1.1	More erodible
Sparse grass							
2	0.10	0.34	+0.24	16.1	0.5	-15.6	Less erodible
		0.22	+0.12		14.1	- 2.0	Less erodible
4	0.18	0.11	-0.07	26.9	3.2	-23.7	Less erodible
Pine litter							
5	0.02	0.01	-0.01	2.3	0.8	- 1.5	Less erodible
7	0.01	0.01	none	2.3	0.8	- 1.5	Less erodible
Burned pine litter							
6	0.02	0.13	+0.11	8.6	6.5	- 2.1	Less erodible
8	0.01	0.00	-0.01	8.1	1.0	- 7.0	Less erodible
Rocky-furrowed							
9	0.00	0.02	+0.02	16.3	9.5	- 6.8	Less erodible
12	0.02	0.02	none	28.0	4.0	-24.0	Less erodible
Rocky-bare							
10	0.23	---	---	108.7	---	---	
11	0.23	0.41	+0.18	104.7	39.9	-64.8	Less erodible

NEW MEXICO

Shallow, calcareous, heavy in texture, slightly alkaline soils, Pecos River watershed. (Smith and Leopold, 1942) Using the North Fork infiltrometer, the authors found mean infiltration rates for wet runs on 24 grassland, 39 woodland, and 63 desert-shrub plots were 1.55, 1.24, and 0.71 in/hr, respectively. These values are significant from each other with exception of the grassland and woodland values. Vegetal density, dispersion ratio, dispersed clay, silt plus clay, and 5-u clay content all were highly correlated with infiltration.

OKLAHOMA

Loamy fine sand. (Rhoades, Locke, Taylor, and McIlvain, 1964) After investigating the effects of 20 years of cattle grazing at four intensities, it was concluded that water-intake rates were inversely proportional to the grazing intensity regardless of the type of equipment used to approximate intake rates. Both a sprinkling infiltrometer and a double-ring infiltrometer were used in the study. Soil loss was negligible regardless of grazing intensity. Bulk density and penetrometer measurements showed that grazing compacted the soil.

SOUTH DAKOTA

Four range sites near Newell. (Rauzi and Kuhlman, 1961) Data from four watersheds showed that water-intake rates were correlated with range sites (delineated by soil type primarily), as mapped by the Soil Conservation Service, where range condition class was comparable. In this study, all sites were classified in good condition. Water-intake during the first 15-minute period of a 1-hour test was high (1.52 to 2.04 in/hr) even on thin or fine-textured soils. However, the intake rate declines much more rapidly on such sites in later periods of a test except on thick well-structured clays which maintained a rate comparable to a sandy loam. Average infiltration rates after 1 hour for various sites were: Sandy, 1.52 in/hr; panspots, 0.36 in/hr; dense clay, 0.40 in/hr; and clayey, 1.26 in/hr.

Friable silty clay or silty clay loam. (Rauzi and Hanson, 1966) Utilizing mixed prairie rangeland watersheds and a mobile infiltrometer, the authors found that water intake rates on differentially grazed rangeland watersheds were nearly linear with the heavily grazed sites having the lowest and lightly grazed sites the highest rate. Table 11 shows some infiltration values obtained under conditions of this study:

Table 11. Air-dry herbage and mulch (lb/acre) and rate of water intake (in/hr) on small native range watersheds grazed heavily, moderately, and lightly. Cottonwood, South Dakota, 1964.

Study area 1/	Total herbage	Mulch	Rate of water intake: First 30-min	Rate of water intake: Second 30-min	Rate of water intake: Ave for 1-hr period
Heavily grazed	910[c]	456[b]	1.40[c]	0.71[c]	1.05[c]
Moderately grazed	1,345[b]	399[b]	2.16[b]	1.21[b]	1.69[b]
Lightly grazed	1,869[a]	1,100[a]	3.19[a]	2.72[a]	2.95[a]

1/ Twelve test plots on each study area. Means with the same letter superscript are not statistically different from each other at the 0.05 level of significance

Grazing was also found to increase runoff, a direct result of decreased infiltration. Heavily grazed watersheds produced the most runoff and lightly grazed watersheds the least. Storm characteristics were found to be dominant factors in production of runoff from areas differentially grazed.

TEXAS

Various soils, western Edwards Plateau. (Thomas and Young, 1954) Cylinder ring infiltrometers were used in this study. The data indicated that initial infiltration rates were highest on tobosagrass sod, followed by buffalo and curly mesquite sod and bare ground. However, the total amount of infiltration at the end of 2 hours was greatest on tobosa sod and bare ground and was significantly lower on buffalo and curly mesquite sod. There were no differences between soil series or different years, and slowest rates under all conditions occurred when drought was most severe.

Medium-textured surface soil underlain by tough clay. (Osborn, 1952) Different water intake capacities on the same soil were caused by differences in the cover on the surface and in the physical and biological conditions of the soil associated with cover conditions.

Various soils in south Texas. (Box, 1961) Four plant communities occurring on three soil types were tested with the ring infiltrometer. Mesquite and chaparral communities occurred on clay, a prickly pear community on clay loam, and a bunch grass community on fine sand. Infiltration rates varied between communities and between conditions within a community. All vegetation improved water intake on the clay soil, but grass proved superior to brush. Under grass sod, an average of 8.9 inches of water entered the ground in 2 hours compared with 7.5 inches under mesquite and 3.5 inches under bare soil.

Various range condition sites, Big Bend-Davis Mountain section. (Leithead, 1959) Ring infiltrometers were used to establish that runoff increased as ranges deteriorated in range condition. A range site in good condition was found to absorb moisture five to six times faster than the same range site in poor condition.

Silty clay loam. (Dee, Box and Robertson, 1966) Infiltration rates (determined with ring infiltrometers) were found to increase with the increasing position of a plant in the successional scale, the stage of succession of the community, the amount of standing vegetation, and litter from previous years. Infiltration rates in soil under different successional stages were significantly different from each other. Soil under blue grama absorbed 8.4 inches of water in a 2-hour period compared with 5.6 inches for windmill grass, 3.8 inches for annual weeds and 2.1 inches for buffalo grass.

UTAH

Selected plant-soil complexes. (Woodward, 1944) Using the Type-F infiltrometer, values were derived representing average infiltration capacities for various plant cover densities on selected plant-soil complexes. This information is presented in Figure 1.

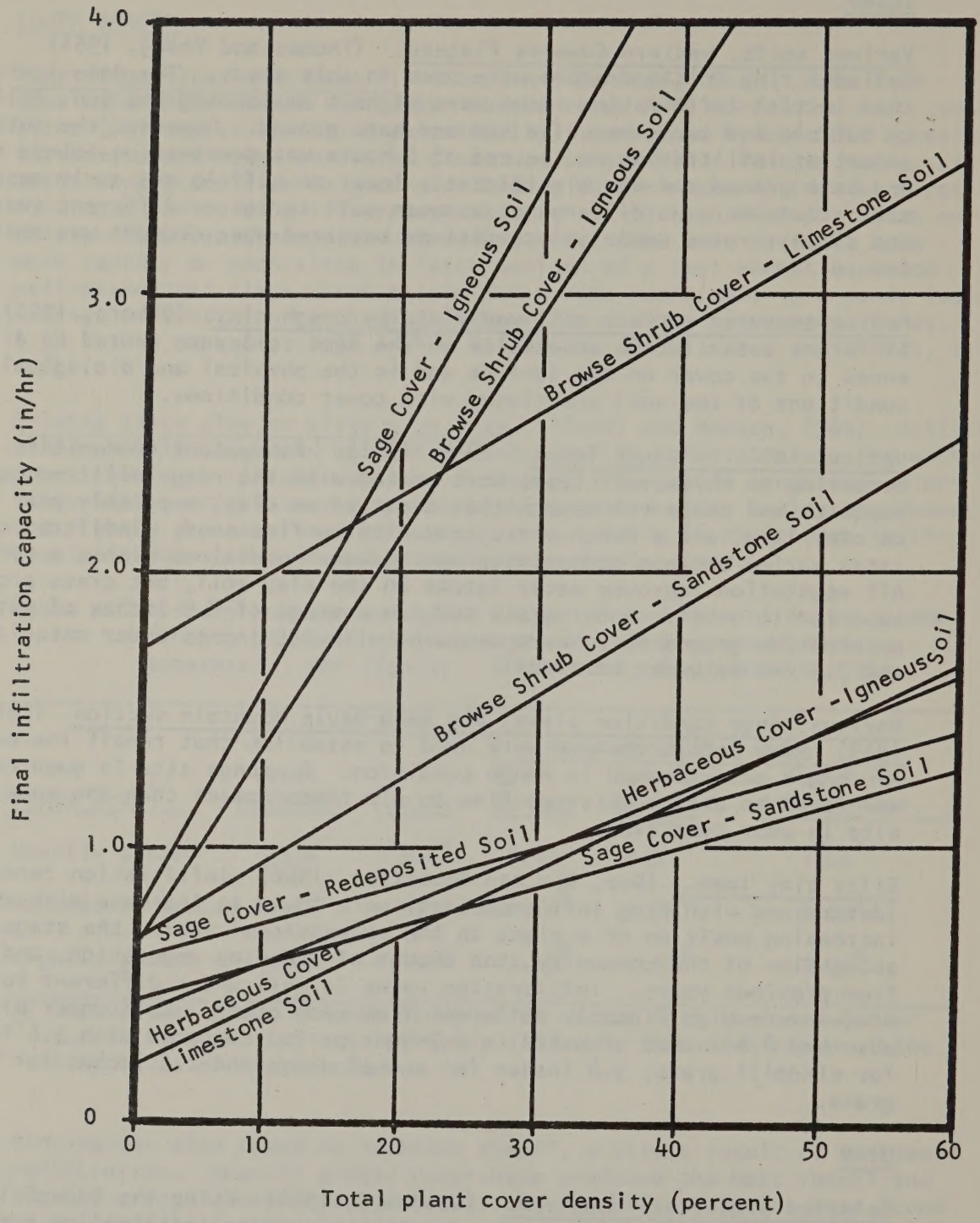

Figure 1. Relationship between final infiltration capacity and total plant cover density for various plant cover and soil complexes.

Sevier Lake Watershed, Utah.

Limestone and shale derived silty clay loams. (Meeuwig, 1965) Using the Rocky Mountain infiltrometer, information was obtained concerning influence of seeding and grazing on infiltration capacity and soil stability on a subalpine range in central Utah. The seeding (various species) did not significantly affect infiltration or soil stability. However, 7 years after discing and seeding, there was decreased organic matter and capillary porosity in the surface soil, greater bulk density, and decreased plant and litter cover. Grazing over the previous 4 years decreased plant and litter cover and noncapillary soil porosity, increased capillary porosity in the surface soil, and decreased infiltration and soil stability.

Soils derived from metamorphic gneisses and schists to conglomerates, sandstones, and shales. (Meeuwig, unpublished manuscript) The author reports a simulated rain study (Rocky Mountain infiltrometer) on 80 plots on ungrazed herbaceous sites in which the influence of vegetative cover density, slope, and soil properties on soil stability and infiltration was investigated. The study was made on the Davis County Experimental Watershed on the Wasatch Forest.

The amount of water retained by a plot (total infiltration) during a 30-minute rain test was found more closely correlated with density of plant and litter cover, as determined by first strikes of a point analyzer, than with any other measured variable (r^2 = .74). Four other site factors (bulk density of surface 4-inches of soil, particles and aggregates larger than 0.5 mm in the surface inch of soil, initial moisture content of the surface 2-inches of soil, and air-dry weight of vegetation) in combination with density of plant and litter cover account for 80 percent of the variance in amount of water retained.

Density of plant and litter cover was found to be the most influential factor affecting quantity of soil eroded (r^2 = .76). Three other site factors -- slope gradient, litter weight, and soil organic matter -- in combination with cover density account for 83 percent of the variance of the logarithm of soil eroded.

Various soils of herbaceous summer range in Utah, Idaho, and Montana. (Meeuwig, unpublished manuscript) This study consisted of measurements of infiltration, soil erodibility, other selected soil properties, vegetative properties, vegetative cover characteristics, aspects, and slope of 464 small infiltrometer plots over a wide variety of conditions of herbaceous summer range in Utah, Idaho, and Montana. Multiple regression equations developed for three different areas account for 65 to 88 percent of the variance in amount of water retained on plots. Influencing factors, besides those mentioned in the above study, were clay content, litter weight, soil capillary porosity, soil organic matter, slope and aspect.

In pooled data from all 464 plots, density of vegetation, litter cover, and plot slope gradient account for 63 percent of the variance of the logarithm of soil eroded. Soil clay content and organic matter account for an additional 6 percent.

Limestone derived residual subalpine soil. (Orr, 1957) Infiltration measurements with a Type FA infiltrometer were made on four treated (plowed and seeded) and untreated sites. Infiltration rates at the end of approximately 1 inch of artificial rainfall varied from 0.27 inch to 3.60 inches per hour, or about the full rate of rainfall application. Rates near the end of 3 inches of rainfall varied from 0.22 to 3.57 inches per hour. There were no over-all significant differences in infiltration between the treated and untreated plots for either 1 or 3 inches of rainfall. Analysis of individual plot data, however, showed infiltration rates to vary directly with amount of ground cover.

Other information (Marston, 1955) indicates that high (12.1 to 38.7 in/day) infiltration rates can be obtained in certain chokecherry and oak brush stands in central Utah. These sites may prove valuable for water spreading projects during periods of surplus streamflow.

WYOMING

Silt loam soil. (Rauzi, 1956) Infiltration rates were found to vary with degree of grazing use on experimental cattle pastures. Final infiltration rates after a 1-hour test with a mobil raindrop applicator on lightly used pastures was 1.20 in/hr as compared to 0.91 in/hr on heavily used pastures. The difference was statistically significant.

Soils derived from cretaceous shale and sandstone, and soils derived from Wasatch conglomerate. (Tigerman, 1952) Using the type FA infiltrometer, comparable infiltration runs were made on both good and poor grass sites inside and outside of totally protected big game exclosures, as well as on some average browse sites. The infiltration capacity was greater and the sediment production was less inside the exclosures where the plant-soil complexes had been protected. The protected browse site had the highest infiltration capacity and the smallest amount of sediment production of all sites studied.

Runoff. Runoff is the difference between rainfall and infiltration, and may be expressed in terms of quantity and/or rate. This parameter is usually measured directly rather than as inferred above, by subtracting infiltration from rainfall. Runoff is initiated when rainponds occupy all available soil surface storage, additional rainfall then causing overland flow and runoff. Timing of these events is primarily related to storm intensity, storm duration, and anticedent soil moisture conditions (Schiff, 1943; Betson, 1964).

Slatyer and Mabbutt (1964) discuss runoff under arid and semiarid conditions, and they state the following:

"Much of the rain falling on the desert surfaces is absorbed by the porous mantle of soil and rock waste or is lost by evaporation. Since desert rainfall is naturally infrequent and short-lived, these initial losses are proportionately greater than in humid regions, so that in general, percentage runoff tends to decrease with annual rainfall and is less than 10 percent in most arid zones.

"The intensity of the rainfall may be more important than the total amount, although runoff will tend to increase with duration of the fall . . .

"Because of high evaporation losses, the degree of slope exercises a stronger control on the amount of runoff than in humid areas. On hill slopes percentage runoff may be as high as in humid uplands, the initial losses being compensated by steeper gradients, bare rocky surfaces, and low wastage through vegetation, but rain falling on gently sloping plains will be less effective in producing runoff than in humid areas.

"In the absence of dense vegetation, the nature of the surface is an important factor in controlling the amount and character of runoff. On desert hill slopes there is little retention of rainfall by the slope mantle and runoff is very rapid. There is also a deficiency of fine material on such slopes, so that surface runoff is underloaded and the length of overland flow is reduced. As a result, a fine meshwork of slope rills is formed and these sink up into a channel network incised to varying degree, depending on rock resistance . . .

"Because of the thinness of soils and sparsity of vegetation, these surfaces offer little storage for rainfall; such runoff as does occur will ensue rapidly, and surface flow will be less restricted than on similar slopes in humid areas. For the same reasons, there can be little feedback from the surface layer, so that runoff will rapidly cease when the rain stops. This leads to a concentration of runoff into short flood phases."

Sediment production is usually associated with runoff. Sediment yields for a given situation vary with total quantity and runoff rate. The actual process is initiated by falling drops striking the land surface followed by runoff in which soil is moved from an area (Cook, 1936). Smith and Wischmeier (1962) emphasize that four factors and their interrelations have long been considered basic determinants of rate of rainfall erosion. These are: (1) Climate, largely rainfall and temperature; (2) soil, its inherent resistance to dispersion and its water intake and transmission rates; (3) topography, particularly steepness and length of slope; and (4) plant cover, either living or the residues of dead vegetation. Anyone of the factors can assume values which, alone, may create a rainfall erosion problem. Other reviews include Smith and Wischmeier (1957), Copeland (1965), and Roehl (1965).

Sheet, rill, and gully erosion are separate phases of the degradation process on rangelands. Though less obvious than the latter two, sheet erosion (defined(Baur, 1952) as removal of a fairly uniform layer of soil or material from the land surface by the action of rainfall and runoff) cannot be ignored as a source of sediment (Glymph, 1957). Various indicators of erosion have been reviewed by Gleason (1953).

Most striking of the erosion processes is the formation of rills, gullys and arroyos (Tarr,1890; Parker, 1897; Rich, 1911; Sampson and Weyl, 1918; Fleming, 1934; Leighly, 1936; Ireland, 1939: Gapen, 1937; Coldwell, 1957). Factors contributing to gully formation are often ill defined. Grazing, intense summer storms, and/or general climatic changes have been noted as possibly contributing to gully or arroyo formation on various landscapes. Some of these aspects for the western United States have been discussed by Bailey (1937, 1941), Bryan (1940), Antevs (1952), Schumm and Hadley (1957), Bull (1964), and Ruhe and Daniels (1965).

Another type of erosion, "piping," may become quite pronounced under certain conditions. This phenomenon appears when the subsoil erodes from under the surface leaving tunnels. Apparently the five following conditions must be present before piping can take place (Fletcher, Harris, Peterson, and Chandler, 1954): (1) there must be a source of water, (2) the surface infiltration rate must exceed the permeability rate of some subsurface layer, (3) there must be an erodible layer immediately above the retarding layer, (4) the water above the retarding layer must be under a hydraulic gradient, and (5) there must be an outlet for the lateral flow.

Various techniques for gully and erosion control have been outlined and/or studied by Deppa (1948), Rosa (1954), Roberts, Bunch and Chiles (1958), Heede (1960), Peterson and Hadley (1960), and Bailey and Copeland (1962).

Avoiding trouble before it starts is one objective of most land managers. Accurate determination of the site by site condition and trend of the plant cover and soil mantle is considered the key to satisfactory range-watershed management (Bailey, 1945). Many unsatisfactory range-watershed situations are attributed largely to inadequate understanding of conditions and trend, including a tendency to rely upon single-factor indices rather than to consider all of the observable site factors.

Following are summarized some of the studies dealing with runoff and sediment production in rangeland environments. Following the same procedure as with infiltration, information is broken down by state and soil type where possible.

ARIZONA

Clay soil of reddish chestnut group. (Martin and Rich, 1948) Utilizing lysimeters in central Arizona, the authors found that: (1) winter runoff was independent of amount of perennial grass vegetation, (2) total runoff was unaffected by grazing, (3) when grazing reduced the amount of perennial grass, there were marked increases in surface runoff and erosion, and a significant decrease in average areal infiltration capacity.

Upland sandy clay loam with a heavy clay subsoil. (Beutner and Anderson, 1943) When rainfall was applied at 1.75 in/hr, the water loss was approximately 20% on mulched plots and approximately 60% on untreated plots. Under natural summer rainfall (July-October) of 6.15 inches, runoff was 57% on bare plots compared with only about 10% on grama covered and grass mulched plots.

Alluvial silty clay loam with considerable alkali. (Beutner and Anderson, 1943) There was a 72% loss of applied rainfall (1.75 in/hr) compared with 28% loss of rainfall from plots covered with grass straw. Under 9.7 inches of natural rainfall (July-March) 73% was lost on unmulched areas compared with 11% on mulched areas.

Upper Gila River basin in southern Arizona. (Peterson and Hadley, 1960) In reviewing the effectiveness of erosion abatement practices on semiarid rangelands in the western United States, the authors include condition of 191 structures located in the upper Gila River basin (Table 12). The structures range from 6 to 10 years in age.

Table 12. Effectiveness of land-treatment structures.

Type of structure	Number examined	Number breached	Effect on vegetation
Small earth diversion dams	37	14	Considerable sediment deposited above dams but vegetation negligible
Hand-placed rock spreader	65	33	Sediment deposited above spreader but no perennial vegetation established
Loose rock spreader	27	16	Little sediment deposition, vegetative recovery negligible.
Brush spreader	30	30	Results negative
Wire and brush spreader	32	16	Fair sediment deposition but no appreciable amount of vegetation established

The authors state that almost complete absence of any appreciable benefits to vegetation from structures of this type, plus the excessive costs of maintenance, precludes the further use of such units in areas where climate and soil conditions are similar to those in southern Arizona. In general, structures like these have been dropped from all conservation programs on rangelands in southwestern United States.

Chaparral watersheds, central Arizona. (Rich and Reynolds, 1963) The authors found that proper grazing (no more than 40% of perennial grass production removed at end of summer growing season) in chaparral grass-shrub complexes had no measurable effect upon water production or erosion.

Another study (Rich, 1961) found that surface runoff and erosion in the chaparral zone were reduced, and a perennial grass cover was established, by cutting and root grubbing shrubs, sloping steep gully sides, placing out brush in gully channels, and then seeding to grass. Hardware-cloth checks placed on the contour also reduced erosion, but did not produce additional vegetation.

Sandy clay loam. (Brown and Everson, 1952) Ten years after contour ripping at 5-ft intervals, a site in the southern Arizona desert grassland produced 2.5 times more grass than the nonripped. The longevity of ripped furrows in this instance appeared to be about 15 years.

Gravelly sandy loam, derived from calcareous base material. (Kincaid and Williams, 1966) Runoff measurements for 1 year revealed no statistical differences between various range improvement treatments (brush clearing, pitting, and seeding to grass). Microrelief measurements indicated that one summer's rainfall reduced roughness due to pitting; and such other surface characteristics as erosion pavement and exposed soil approached a state of stability similar to the untreated plots.

Bare soils, Sierra Ancha Experimental Forest. (Cooperrider and Hendricks, 1940) During a torrential summer storm, some bare spots no larger than 30 feet in diameter became the source of destructive surface runoff and mudflow that ran downwards through well-revegetated areas, opening former gullies and causing new destruction.

Stony clays. (Skau, 1960) A study of precipitation disposition was made in the Utah juniper type of northern Arizona. Small plots revealed that depression storage, subsurface flow and percolation were negligible factors on these sites. Large amounts of surface water movement occurred on plots having shallow soils. Surface water movement seldom occurred where juniper litter covered the ground.

Skau (1961), in another study, found that pits created by cabling juniper, and the juniper debris left on the ground, helped to reduce the amount of surface water flow by an estimated 0.09 to 0.27 inch annually.

CALIFORNIA

Grassland vs pine site. (Kittredge, 1954) In a region of approximately 30 inches annual precipitation, surface runoff in grassland did not start until the seasonal rainfall reached 3 to 12 inches. Total seasonal surface runoff averaged 3.79 inches from the grassland and 0.61 inch in the pine. Seasonal erosion per inch of surface runoff was 0.13 metric tons per acre from the pine compared with 0.03 from the grassland.

Permeable, stony, sandy loam, San Dimas Experimental Forest. (Rowe and Reimann, 1961) During the process of converting from dense scrub oak chaparral to grass on 1/40th-acre plots, there were small increases in surface runoff and erosion before a complete grass cover was established. Following establishment of a complete grass cover (1 year), there was no appreciable amount of runoff or water-carried erosion from the plots. Water losses and soil moisture relations, however, were markedly altered by the changes in vegetation.

Winter scour from surface runoff and "dry creep" from steep side slopes during the summer are also influenced by vegetation changes at San Dimas (Anderson, Coleman, and Zinke, 1959; Krammes, 1960). The former study had found that under long unburned conditions, dry-season debris movement exceeded wet-season movement on most study sites. Following a burn (the latter study), south slopes flanking rejuvenated stream channels yielded 10 times the preburn debris rate, nearly 89 percent of which came during the dry season. Other study sites showed similar large increases of 4 to 17 times the pre-fire rates. Much of the debris accumulated in stream channels where high flows would eventually carry it to valleys below.

Several wildland soils. (Wallis and Stevan, 1961) This paper reported that soil erodibility indices were related to amount and kind of cations present in the soil. To accomplish this, erodibility of 20 soils was indexed using Middleton's dispersion ratio and Anderson's surface-aggregation ratio. Of the four most plentiful soil cations (Ca, Mg, K, and Na), linear and curvilinear terms involving Ca and Mg were significant when used to predict an erosion index.

A similar study (Andre and Anderson, 1961) utilized the above data, and in addition, included the soil-forming factors of geology, vegetation type, elevation, and zone to compute an erosion index. This technique improved the predictability of erodibility reported by Wallis and Stevan by 30 percent ($r^2 = .63$). Soil developed from acid igneous rock was about 2½ times as erodible as soil developed on basalt. Erodibility was highest for soils under brush, next under trees, and least under grass. No clear-cut relation of erodibility to elevation was found.

Various soils, southwestern Riverside County. (Pillsbury, Pelishek, Osborn, and Szuszkiewicz, 1962) Paired plots (50 x 50 ft) and one set of small paired watersheds were utilized during the 1942-1959 period to study effects of vegetation manipulation of chaparral-covered watersheds on surface runoff and erosion. Results indicated there was an increase in surface runoff with conversion from vegetative cover of brush to one of grasses and forbs. This appeared to be related primarily to the temporary detention of precipitation in the litter under brush found in that region. There was sometimes, but not always, a marked increase in erosion during the conversion process.

Sandy clay loam. (Rowe, 1948) Nine years record of total, yearly, and major-storm records all showed that burning chaparral vegetation increased surface runoff and erosion. During the 1929-1938 period, when total precipitation was 302.43 inches, a total of 42.91 inches of surface runoff and 113 tons of surface soil per acre was recorded for the annually burned plots, 5.64 inches and 4 tons of soil per acre for twice-burned plots, and 0.11 inch and just a trace (12 lb per acre) from undisturbed plots. Yearly records show that the undisturbed woodland-chaparral type was effective in minimizing runoff and erosion during the years of high as well as low precipitation.

Various sites, central and southern California. (Rowe and Colman, 1951) Working in the Sierra Nevada's and San Gabriel Mountains, the authors found that annual burning of woodland chaparral reduced interception loss and increased surface runoff due to decreased infiltration capacity of the soil. Annual evapotranspiration was not appreciably changed by burning. Thus, owing to the reduced interception loss, total water yield of the burned plots was slightly greater than that of the natural plots. This increase was achieved by greatly increased storm flows of surface runoff, often heavily charged with sediment, and correspondingly reduced percolation.

Several sites, northern California. (Sampson, 1944) Working primarily in Shasta and Mendocino Counties, the author found that soil erosion from gullies generally increased after burning, especially on grazed areas. Formation of new gullies was noted on heavily burned steep slopes that were subsequently pastured. In contrast, little erosion occurred, regardless of degree of slope, on ungrazed areas where the topsoil was covered with rock fragments and pebbles. After a gully was formed, invading chaparral apparently exercised little control over erosion.

Ring infiltrometer results showed differences in infiltration capacity at the end of a summer-dry season between similar burned and unburned soils on three areas to be significant.

Soil moisture studies revealed that at the end of the summer drought, the upper levels of soil on both burned and unburned plots contained approximately the same amount of moisture.

COLORADO

Various soils, Badger Wash Basin. (Lusby, Turner, Thompson, and Reid, 1963) Comparison of runoff in grazed and ungrazed watersheds indicates a change in the relation between precipitation and runoff because of exclusion of livestock. More sediment per unit area was produced during 5 years of study from grazed than from ungrazed areas. With respect to infiltration, initial water-absorbing capacity increased significantly on ungrazed plots after 5 years.

In another study, on soil derived from Mancos Shale (Hadley and Lusby, 1967), runoff and hillslope erosion resulting from a high-intensity thunderstorm were measured in a small basin of 12 acres. A total of 1.10 inches of precipitation was recorded in 6 hours, the maximum 10-minute intensity being 1.98 inches per hour (probably a 25-year storm). The total runoff as measured in a reservoir was 0.508 inch over the basin, and 0.90 inch of precipitation had been recorded when runoff stopped. Data from measurements of erosion pins along 6 hillside profiles indicated that approximately 0.11 acre-foot was eroded from the basin during the storm; survey of the reservoir showed that 0.090 acre-foot was delivered to the lower end of the basin.

Alluvial derived soils, relatively permeable. (Dunford, 1949, 1954) Bunchgrass plots (Arizona fescue and mountain muhly) 1/100th of an acre in size were utilized for this study on the Manitou Experimental Forest. Results indicated a significant increase in erosion and runoff from heavy grazing (2½ acres per cow month) while erosion from moderately grazed (4 acres per cow month) and check plots remained near normal. In practice, it appeared that moderate grazing on relatively gentle slopes is permissible if the increased loss of runoff water does not cause critical moisture shortages for plant development.

IDAHO

Granitic mountain soils. (Craddock and Pearse, 1938) Four range types (wheatgrass, downy chess, lupine-needle grass, and annual weed) were selected for study using an infiltrometer with plot size approximately 6.6 by 33 feet (0.005 acre). Wheatgrass range (*Agropyron inerme* with about 35% density) was superior to other existing range types for controlling runoff and erosion. In the lupine-needle grass and annual weed type, high-and moderate-intensity rainfalls caused large amounts of runoff and erosion.

Downy chess (cheatgrass) had considerable erosion control value, especially since it was able to grow on impoverished soil and could act as a first aid until more desirable watershed plants could become established. Because of the sharp increase in erosion that followed soil disturbance on the 40% slopes, the indication was that cheatgrass slopes steeper than 30% should not be grazed. Table 13 presents some quantitative data from the study.

Table 13. Runoff results under each of eight experimental conditions on the four vegetation areas.

Slope, intensity of rainfall, and soil treatment	Runoff percent of applied rainfall: Wheatgrass	Downy chess	Lupine-needlegrass	Annual weed	Average of types
30-percent slope:					
Moderate-intensity rainfall:					
Undisturbed soil.....	0.7	9.8	43.5	46.1	33.1
Disturbed soil.....	.2	4.9	54.9	62.0	40.6
High-intensity rainfall:					
Undisturbed soil.....	.8	4.7	56.5	53.9	38.4
Disturbed soil.....	.4	29.4	67.3	61.9	52.9
40-percent slope:					
Moderate-intensity rainfall:					
Undisturbed soil.....	.3	25.6	44.1	60.9	43.5
Disturbed soil.....	.2	25.6	24.1	59.7	36.5
High-intensity rainfall:					
Undisturbed soil.....	.2	53.3	54.7	71.8	59.9
Disturbed soil.....	.3	50.4	54.2	69.8	58.1
30-percent slope, mean.....	.7	12.2	55.55	55.98	41.24
40-percent slope, mean.....	.13	38.72	44.28	65.55	49.52
Moderate-intensity rainfall, mean	.5	16.48	41.65	57.18	38.43
High-intensity rainfall, mean.	.6	34.45	58.18	64.35	52.32
Undisturbed soil, mean.....	.7	23.35	49.70	58.18	43.74
Disturbed soil, mean.....	.4	27.58	50.12	63.35	47.02
General mean.....	.4	25.5	49.9	60.8	45.4

Another study by Packer (1953) considered the influence of artificial trampling on bluebunch wheatgrass and cheatgrass ranges which normally had sufficient protective cover (70% or more, composed of aerial plant cover plus litter, rock, or otherwise). Following artificial trampling, a modified type F infiltrometer was used for evaluating treatments. Results indicate that if a site had 90 to 95% initial ground cover, then overland flow and soil erosion were maintained at a safe level even under 60% trampling disturbance. When initial ground cover on wheatgrass and cheatgrass sites was in the range of 70 to 85 percent, then trampling disturbance from 20 to 40% caused increased overland flow and soil erosion beyond that which was considered a safe minimum.

Renner (1936) determined the influence of several natural and introduced factors on erosion on the Boise River Watershed. Variance in erosion associated with each of seven factors, expressed in percent, appears in ascending order of importance as follows:

Gradient	2.9
Rodent infestation	4.9
Plant density	6.8
Aspect	10.6
Soil conditions	12.8
Plant type	13.4
Cumulative effect of past grazing as expressed by accessibility of range to livestock	15.3

Above results indicated that grazing, and more particularly overgrazing, and its attendant effects of depletion of plant cover and litter and trampling of the soil, was the most important factor contributing to erosion. To control the accelerated erosion on the watershed, the author recommended that plant cover be restored to at least 30 percent, that the rodent population be reduced, and that range and livestock management improvements be initiated which would relieve conditions on areas particularly susceptible to erosion.

MONTANA

Various soils, Gallatin elk winter range. (Packer, 1963) This study indicated that management objectives for restoring and maintaining soil stability on the Gallatin elk winter range include ground cover densities of at least 70% and soil bulk densities no greater than 1.04 gm/cc.

Typical rangeland soils in eastern Montana. (Monson and Quesenberry, 1940) This study objective was to further range improvement through conservation of flood waters. Results indicate that free flooding is adapted to lands having slopes as steep as 5 percent. The method of meandering flooding was adapted to slopes of less than 1½ percent (for steeper slopes contour spreading ditches should be used), and ponding was restricted to fairly level areas. Grass production increased where water concentrated.

NEW MEXICO

Sandy loams to silty clays. (Aldon, 1964) Due to the initiation of a grazing management program on the more deteriorated portions of three San Luis Experimental Watersheds, watershed conditions improved over a 3-year period. Average ground cover doubled, bare ground decreased, and sediment production decreased between 0.2 and 0.7 acre-foot per year on the watersheds.

Various sites in upper Gila River and Mimbres River Basins. (Peterson and Branson, 1962) Appraisals were made to determine effectiveness of various land treatment measures constructed by the CCC in the mid 1930's with respect to vegetation improvement, longevity of structures, quantities of sediment retained. Treatments included earth fill dams, earth dike spreaders, loose rock spreaders, hand placed rock spreaders, brush spreaders, "cement worm" spreaders, cable and wire spreaders, and rock rubble gully control structures. More than half of the structures were breached within a few years after construction. The highest percentage of failures occurred in the loose rock spreaders, brush and rock spreaders, and rock rubble structures. Where earth dikes were not breached and water reached the spreader system, there was improvement in vegetation even in the driest areas at lower altitudes.

Various alluvial, colluvial and residual soils, derived from sandstones and shales. (Hubbell and Gardner, 1950) The authors report quantitative observations of the effects of soils and native vegetation of diverting all the water and sediment from three arroyos on the Fiquerido Creek drainage basin on the Navajo Experiment Station. Indications were that spreading areas should be of such size that most of the sediment will settle on the upper 20 percent, and they must be large enough to accommodate exceptionally large flows if a severe erosion hazard at the lower end is to be avoided. Slope of the spreading area should not be steeper than 2 percent. In addition, spreading of runoff from badlands and other sparsely vegetated areas was deemed inadvisable except as a means of storing sediment and thus protecting areas and installations at lower levels.

Several semidesert rangeland soils. (Valentine, 1947) Five types of structures to check runoff water from semidesert lands were tested: (1) widely spaced terraces; (2) small diversion dams with brush "hedges" placed to conduct the diverted water over depleted rangeland; (3) contour channels; (4) brush "dams"; and (5) various smaller closely spaced contour earthen structures. No type of structure used was found effective in bringing about improvement in vegetation cover. Soil factors were thought responsible for the failure.

Fine-textured, shale derived soils. (Hickey and Dortignac, 1964) Using runoff plots 10 feet wide and 31 feet long near Cuba, New Mexico, the authors evaluated relative effectiveness and duration of mechanical treatments produced by a soil ripper and soil pitter. Ripping reduced surface runoff 96 percent and erosion 85 percent in the first year after treatment compared with reductions of only 12 to 24 percent of surface runoff and 16 percent in erosion the first year with pitting. After 3 years, reductions on the ripped area amounted to 85 percent for runoff and 31 percent for erosion compared with only 10 percent for runoff and none for erosion on pitted plots.

Deteriorated range in Southwest. (Hendricks, 1939) The author has noted that on deteriorated ranges, several species of pricklypear cactus conserve soils and check erosion by extending their stems on the surface of the ground, thereby holding litter and silt. The brown-spined pricklypear *(Opuntia phaeocantha)* is one of the most effective species in this respect.

OKLAHOMA

Soils underlain by sandstone and shales. (Daniel, Elwell, and Cox, 1943) Plot studies (1/100 of acre) revealed the most effective method of controlling erosion was with thick-growing vegetation, and of this, grass was the best erosion-resistant cover. Native grass alone, or mixed with Bermuda grass, allowed virtually no soil loss. Burning litter and vegetation on woodland increased soil and water losses 11 and 32 times as compared with undisturbed woodland.

SOUTH DAKOTA

Various soils on typical grassland watershed. (Allis and Kuhlman, 1962) Data on runoff and sediment production were collected during a 3.5-year period from 16 grassland watersheds ranging in size from 30 to 13,000 acres. There was more than three times as much runoff from fine textured soils derived from shale as from medium textured soils derived from sandstones and shale on the rangeland watersheds.

Panspots vs sandy range sites. (Kuhlman and Hanson, 1966) Two years of record indicates that panspot watersheds yielded about six times more runoff than sandy watersheds. Annual runoff from approximately 14 inches of precipitation was 0.98 and 0.16 inch from the panspots and sandy range site watersheds, respectively. Snowmelt runoff from the panspots watersheds amounted to about one-fourth of the annual runoff, whereas snowmelt runoff from sandy watersheds was almost negligible.

Clayey range sites. (Sharp, Bond, Neuberger, Kuhlman, and Lewis, 1964) One year's measurement of runoff on ranges subjected to light, moderate, and heavy grazing for about 20 years indicates that runoff normally increases with grazing pressure. Under conditions of unusually abundant rainfall, grazing differences are not reflected in resultant runoff data.

TEXAS

Grassland soils near Spur. (Dickson, Langley, and Fisher, 1940) Grassland sites listed on contours have shown increases in available soil moisture and depth of moisture penetration. Effects of the added moisture include greater forage yields, green grass for longer periods, and increased cover.

Heavy sandy loam soil. (Whitfield and Fly, 1939) Studies of pasture furrowing were made near Dalhart and Hereford, Texas. It was found that moisture penetrated deeply in furrows and formed a reservoir upon which adjacent growing plants could feed. Penetration was uniformly shallow on non-furrowed land. Small, closely spaced furrows distributed soil moisture more evenly. Best vegetation responses occurred when ranges were furrowed in the spring.

UTAH

Typical mountain soils, northern Utah. (Bailey and Copeland, 1960) Two adjacent mountain watersheds were compared in this study. One had no history of watershed plant cover depletion or floods while the other produced damaging mudrock floods in 1930 following destruction of vegetation on the headwater lands. Vegetation was restored on the depleted and eroded areas by contour trenching and reseeding prior to the start of stream flow records.

The rehabilitation measures effectively controlled summer storm floods from the previously poor condition watershed. This control was accompanied by a decrease of 2.70 inches in annual runoff over the 22-year period, 83% of which occurred in the first 11 years.

Various range watershed soils. (Croft, Woodward, and Anderson, 1943) Laboratory studies showed soil losses and physical and chemical changes caused by excellerated erosion are greatest on watersheds where grazing has been heaviest, and smallest where grazing has been lightest. Results strongly suggest that grazing management is as much a problem of soil management as of forage management.

Compact sandy loam soil under aspen. (Marston, 1952) Results from 23 summer storms showed erosion to be negligible when 5% or less of the rainfall ran off as overland flow. Erosion rates increased rapidly with greater amounts of storm runoff. During major storms, with rainfall rates in excess of 3.00 in/hr, a ground cover of at least 65% is needed to keep runoff during such storms to less than 5%.

Subalpine residual clays and clay loams derived from limestone and bituminous shales. (Meeuwig, 1960) A review of the history of two experimental subalpine watersheds in central Utah shows that such areas, under proper management, can be restored from a state of extreme instability and low productivity to a point where grazing, if carefully controlled, can be permitted. Techniques for restoration included contour trenching and seeding as well as exclusion of all grazing. (See also Stewart and Forsling, 1931).

Several rangeland soils in Wasatch Mountains. (Olson, 1949) For the six watersheds which were studied (ranged in size from 6,221 to 18,147 acres), the most obvious relation observed between accelerated erosion and soils concerned the depth of friable (all soil materials that are readily permeable to water) material over bedrock or tight subsoils. Those soils that have friable surfaces underlain by tight clay or bedrock at shallow depths occupy only one-fifth the total area studied, but on them occurred 85% of the severe erosion.

Various sites, Utah, Idaho, and Colorado. (Rosa, 1951) The purpose of this paper was to describe methods of relating existing sediment observations at stream gaging stations, reservoirs, and plots to broad classes of plant cover and soil conditions on both large and small drainage basins. It was shown that sediment measurements at downstream points in either large or small drainage basins can be related to upstream watershed conditions. Derived sediment rates gave reasonable values for western watersheds where actual measurements were available. Relative rates of sediment production for several drainage basins generally averaged about four times as high for poor watershed conditions compared to good. Table 14 gives sediment production by cover conditions from infiltrometer silt samples taken in Utah and Colorado.

WYOMING

Native rangeland soils. (Barnes, 1952) Plot studies revealed that pitting at a 5-foot spacing interval increased infiltration capacity by 50%, increased grazing capacity by one-third, and the effects of the pitting were still being shown 10 years after installation. Grooving at 2-foot intervals or similar treatments can be expected to accomplish similar results to pitting but at higher cost. A killifer failed to increase forage production at any furrow spacing.

Various soils, Box Creek Basin. (Hadley and McQueen, 1961) This study was concerned with use of water by a water-spreading system in Box Creek Basin. It consisted of 27 small dams that diverted flow directly onto a flood plain, where it was used to irrigate a hay meadow. Two years of inflow-outflow data indicate a loss of 34 percent of surface flow entering the spreader system. Suspended-sediment load caused by two storms was reduced 75 percent as a result of spreading.

Table 14. Sediment production by cover conditions from infiltrometer silt samples, Utah and Colorado.

Plant-soil complex	Sediment production				Relative sediment rate			
	Good cover	Fair cover	Poor cover	Bare	Good cover	Fair cover	Poor cover	Bare
	A ft per sq mi							
Sevier R, Utah 1941[1/]								
Browse, limestone	0.01	0.13	0.65	1.00	0.1	1.0	5.0	7.7
Browse, sandstone	.01	.10	.28	--	.1	1.0	2.8	---
Browse, igneous	.01	.03	.30	.50	.3	1.0	10.0	16.7
Average	--	--	--	--	.2	1.0	6.0	12.0
Sage, sandstone	.06	.13	.23	--	.5	1.0	1.8	---
Sage, igneous	.01	.05	.28	.80	.2	1.0	5.6	16.0
Sage, alluvium	.01	.03	.10	.25	.3	1.0	3.3	8.3
Average	--	--	--	--	.2	1.0	3.6	12.0
Grass, limestone	.06	.41	1.05	--	.2	1.0	2.6	---
Grass, sandstone	.20	.36	1.23	2.40	.6	1.0	3.4	6.7
Grass, igneous	.13	.26	.60	.85	.5	1.0	2.3	3.3
Average	--	--	--	--	.4	1.0	2.8	5.0
Wasatch Front, Utah 1941-47[2/]								
Grass, conglomerate	.03	.11	.45	--	.3	1.0	4.1	---
Grass, alluvium	.02	.14	--	--	.1	1.0	--	---
Grass, alluvium	.04	.17	.55	--	.2	1.0	3.2	---
Grass, alluvium	.03	.23	.52	--	.1	1.0	2.3	---
Average	--	--	--	--	.2	1.0	3.2	---
Sage, alluvium	.02	.09	.34	--	.2	1.0	3.8	---
Sage, alluvium	.01	.05	.20	--	.2	1.0	4.0	---
Average	--	--	--	--	.2	1.0	3.9	---
South Platte River Colorado, 1948[3/]								
Grass, granite	.07	.17	.27	--	.4	1.0	1.6	---
Grass, schist	.06	.10	.19	--	.6	1.0	1.9	---
Grass, igneous	.07	.11	.20	--	.6	1.0	1.8	---
Grass, sedimentary	.10	.20	.32	--	.5	1.0	1.6	---
Average	--	--	--	--	.5	1.0	1.7	---
Conifer, granite	.08	.14	.21	--	.6	1.0	1.5	---
Browse, granite	.04	.11	.28	--	.4	1.0	2.5	---
Pine (grass), granite	.12	.17	.21	--	.7	1.0	1.2	---
Average	--	--	--	--	.6	1.0	1.7	---

1/ 108 type "F" runs for 2.5-inch storm. Plant cover density: Good, 40%; Fair, 15%; Poor 5%; Bare, 2%.
2/ 43 type "F" runs for 1.5-inch storm. Ground cover and litter density: Good, 85%; Fair, 45%; Poor, 15%.
3/ 71 type "FA" runs for 1.7-inch storm. Ground cover and litter density: Good, 85%; Fair, 55%; Poor, 20%.

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